Determination Gamma Width and Transition Strength Of Gamma Rays from $^{48}Ti(n_{th}, 2\ gamma)^{49}Ti$ Reaction

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ABSTRACT

The experiment was setup on the 3rd horizontal channel of Dalat nuclear reactor. The sample was activated by thermal neutron which is about 10^6 neutron/cm^2/s. The gamma-gamma system is used to collect experimental data. The Summation of Amplitude Coincidence Pulses method (SACP) treats the experimental data. In this paper, the gamma cascades based on $^{48}Ti(n_{th}, 2\ gamma)^{49}Ti$ reaction. Event – event coincidence method got relative intensity, gamma ray energy directly, and the gamma cascades collected directly as well. Since then, the transition probabilities and some intermediate quantum characteristics are splitted and determined. The single particle model is applied to treat the results. The advantage of this method is that it allows determining a pair of the transitions and the intermediate levels directly. The branching ratios of such gamma transitions are used to calculate the partial gamma width, the total gamma width, lifetime of level. Besides, the transition strengths have been calculated for gamma transitions.

KEY WORDS: *Gamma cascade; Gamma width; Transition strength; Lifetime; Level; Spin and parity*

I. INTRODUCTION

The ^{49}Ti nucleus, with two protons and one neutron hole outside the doubly magic ^{48}Ca, constitutes a very good test for shell-model calculations. The studies of gamma decay of ^{49}Ti have been previously published in many works based on two ways: on accelerator and on reactor. The results on ^{50}V(t, α)^{49}Ti, ^{50}Ti(d, t)^{49}Ti, ^{48}Ca(α, 3n)^{49}Ti [6, 10] showed spin and parity of ^{49}Ti ground state is $7/2^-$ and compound state is $1/2^+$. Those results provided 0÷5 MeV energy arrange. Activation of ^{48}Ti by neutron is the method which is usually to do on the nuclear reactor. Those previously studies showed gamma rays, levels… more than research on accelerator [4, 7, 8]**.** The same results in two ways of study are agreed with spin and parity of ^{49}Ti at compound state and ground state. Almost previous works used a Multi Channel Analysis (MCA) system to get experimental data that could not determine gamma cascade energy, intensity of a pair of gamma cascades which were determined by Ritz algorithms.The lifetime of these levels: 1381 keV (<5ps), 1585 keV (<11ps) and 1762 keV (<14 ps) were determined [2], but high levels were incomplete.

In this experiment, to get experimental data by gamma-gamma coincidence system which treats by SACP method therefore it reduced background effectively.

II. THEORY

The intensity of gamma cascade is a function which depends on gamma width level:

$$I_{\gamma\gamma} = \sum \frac{\Gamma_{\lambda i} \times \Gamma_{if}}{\Gamma_i \times \Gamma_\lambda} \quad (1)$$

where $\Gamma_{\lambda i}$ and Γ_{if} are the partial widths of the transitions connecting the levels λ→i→f; Γ_i and Γ_λ are the total width levels of the decaying states λ and i, respectively.

In this experiment, the relative intensity of gamma cascade transfer was calculated:

$$I_i^{\gamma\gamma} = \frac{S_i^{\gamma\gamma}}{\sum_1^n S_i^{\gamma\gamma}} \quad (2)$$

$S_i^{\gamma\gamma}$ is the calibrated area of ith peak in the cascade transfer.

If J^π is spin and parity of the ground state of nucleus, the spin and the parity of the compound nuclear as capturing neutron (s wave neutron capture) are ability $J^\pi \pm 1/2$. Because the lifetime of nuclei at excited states is very short, gamma radiations emitted from compound nuclei are usually electric dipole (E1), magnetic dipole (M1), electric quadruple (E2) or a mixture of M1 + E2. Selection rules for the multiple order of radiation are identified by:

$$|J_i - J_f| \le L \le J_i + J_f \tag{3}$$

here, L is multiple order, J_i is the spin of the initial state, J_f is the spin of the final state.
When the electromagnetic transfer, the parity is conservative:

$$\pi_i \pi_\gamma \pi_f = 1 \tag{4}$$

π_i is the parity of initial level, π_f is the parity of final level π_γ is the parity of gamma ray.
For electric transfer:

$$\pi_\gamma = (-1)^L \tag{5}$$

For magnetic transfer:

$$\pi_\gamma = (-1)^{L+1} \tag{6}$$

The total gamma width (Γ_γ) of an excited state of a certain mean lifetime (τ_m) is given by:

$$\Gamma_\gamma = \frac{\hbar}{\tau_m} = \frac{\hbar \times \ln 2}{t_{1/2}} \tag{7}$$

where ħ is the Dirac constant = 0.658212×10^{-15} eV.s and $t_{1/2}$ is lifetime of level.
If two or more γ-rays de-excited from the same state, then the partial gamma width of ith gamma transition ($\Gamma_{\gamma i}$) is:

$$\Gamma_{\gamma i} = \Gamma_\gamma \times B_{\gamma i} \tag{8}$$

where $B_{\gamma i}$ is the branching ratio of ith gamma ray, and it is obtained from the following equation:

$$B_{\gamma i} = \frac{I_{\gamma\gamma i}}{I_{tot}} \times 100\% \tag{9}$$

here, $I_{\gamma\gamma i}$ is the intensity of ith gamma transition and I_{tot} is the total intensity.
From the total gamma width, we can calculate the transition strengths of *E1*, *M1* and *E2.*
Components of the gamma rays are defined by the following [5]:

$$|M(E, M(L)|^2 = \frac{\Gamma(E, M(L))}{\Gamma_{\gamma wu}(E, M(L))} \tag{10}$$

where, $\Gamma(E, M(L))$ is the partial gamma width of electric transfer, magnetic transfer, L is multiple orders. In Weisskopf units can be obtained from the following relations in equations:

$$\Gamma_{\gamma wu}(E1) = 6.7492 \times 10^{-11} A^{2/3} E_\gamma^3 \tag{11}$$

$$\Gamma_{\gamma wu}(E2) = 4.7925 \times 10^{-23} A^{4/3} E_\gamma^5 \tag{12}$$

$$\Gamma_{\gamma wu}(M1) = 2.0734 \times 10^{-11} E_\gamma^3 \tag{13}$$

where, *A* represents the mass number of the nucleus and E_γ is the energy of the gamma transitions in keV units.

III. EXPERIMENT AND METHOD

Experimental sample is natural titan. The isotope ratio of the titan samples and thermal neutron capture cross sections are: ^{46}Ti (8.25%; 0.600 barn), ^{47}Ti (7.44%; 1.600 barn), ^{48}Ti (73.72%; 7.900 barn), ^{49}Ti (5.41%; 1.900 barn) and ^{50}Ti (5.18%; 0.179 barn), respectively [1].The neutron beam, sample and detector were set up for maximum efficiency of gamma detection. In this experiment the sample is set at 45^o from neutron beam, two detectors are placed opposite (180^o) with each other. The thermal neutron flux at sample position was about 10^6 n/cm^2/s. Cadmium coefficient is 900 (1 mm in thickness).

The experimental system was a gamma – gamma coincidence spectrometer with the event-event counting method, as shown in Fig. 1. The operating principle was briefly described as follows: The signals from two detectors were amplified and shaped by the amplifiers (Amp. 7072A), that convert the output signals from the amplifiers to digital signals when the conditions of 7811R interfacing part are satisfied. Timing signals from the two detectors were amplified and shaped by Timing Filter amplifiers (TFA 474). The output signals from

TFA 474 went through the Constant Fraction Discriminators (CFD 584). There were two output signals from the CFDs, one was directly sent to Start input and the other was delayed before coming to Stop input of TAC 566. The linear output signal of TAC went to the input of ADC 8713, and the valid convert used for control of three coincidence gates of ADCs. ADC 8713 was used for the timing channel while two other ADCs 7072 were used for the energy channels.

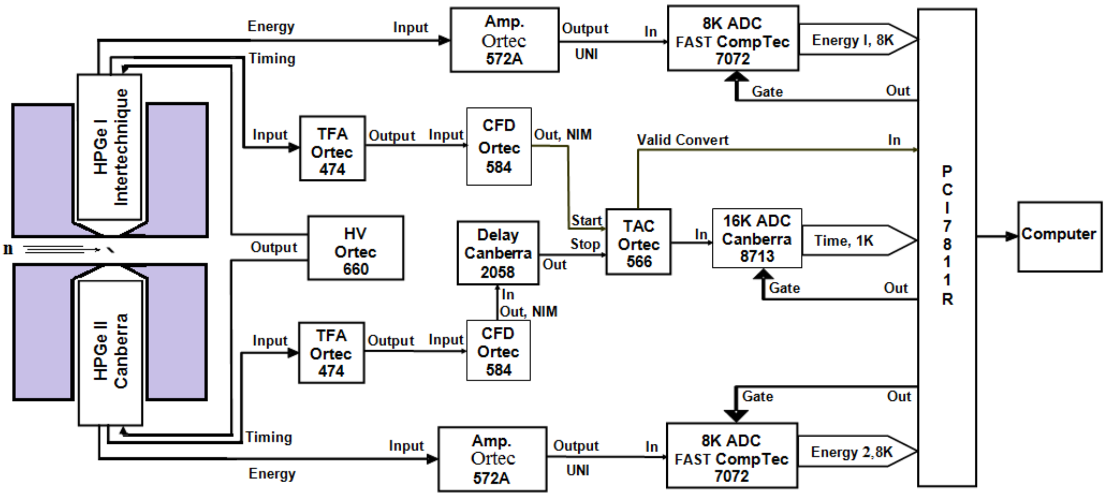

Fig. 1. The experimental system for gamma-gamma coincidence measurement [9]

IV. RESULTS AND DISCUSSION

Energy, relative intensity, spin, the intermediate level of two-step cascade transfer

The time for titan sample measurement was about 300 hours. The numbers of event – event coincidence are about 30×10^6 events, the statistic counts of sum peak at B_n (B_n: neutron binding energy) are about 12000. Table 1 showed information of sum peaks, Fig. 2 is a part of sum spectrum of ^{49}Ti.

Table 1. The information of sum peaks

No	Sum peak energy (keV)	Final level (keV)	Spin and parity of final level
1	8142.50	0	$7/2^-$
2	6761.08	1381.42	$3/2^-$
3	6419.04	1723.46	$3/2^-$
4	3260.38	0	$7/2^-$
5	3175.64	0	$7/2^-$

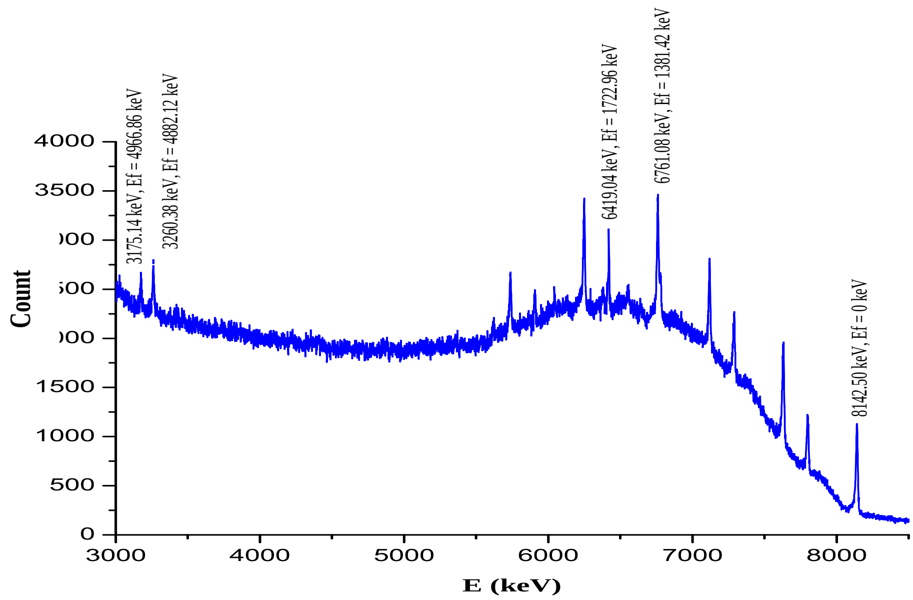

Fig. 2. A part of sum spectrum

Table 2. Some experimental data obtained from the $^{48}Ti(n,2\gamma)^{49}Ti$ reaction

$E_{\gamma1}$(keV)	E_L (keV)	$E_{\gamma2}$ (keV)	$I_{\gamma\gamma}$ ($\Delta I_{\gamma\gamma}$) (%)
E1+E2 = 8142.50 keV, E_f = 0 keV			
6761.08(101)	1381.42	1381.42(070)	46.300(269)
6556.06(079)	1586.44	1585.44(083)	5.919(312)
E1+E2 = 6761.08 keV, E_f = 1381.42 keV			
6419.04(078)	1723.46	341.29(050)	4.145(437)
4966.86(098)	3175.64	1793.47(089)	2.703(213)
4713.83(122)	3428.67	2046.50(092)	0.494(104)
4353.78(133)	3788.72	2405.54(105)	0.468(231)
3920.73(164)	4221.77	2839.60(121)	1.561(311)
3026.62(135)	5115.88	3733.71(156)	2.626(376)
E1+E2 = 6419.04 keV, E_f = 1723.46 keV			
3920.73(164)	4221.77	2498.55(113)	0.999(102)
3475.68(164)	4666.82	2943.61(132)	2.175(78)
3026.62(135)	5115.88	3389.66(154)	1.045(94)
E1+E2 = 3260.38 keV, E_f = 0 keV			
1498.43(077)	1761.95	1761.46(071)	10.203(167)
1674.45(054)	1585.93	1585.44(083)	2.292(134)
E1 + E2 = 3175.64 keV, Ef = 0 keV			
1793.47(089)	1381.67	1381.42(070)	7.324(209)

Note: E1 (keV) is the energy of primary gamma rays; E2 (keV) is the energy of the secondary gamma rays; E_L (keV) is the energy of the intermediate level; $I_{\gamma\gamma}$ (%) and $\Delta I_{\gamma\gamma}$ (%) is intensity and intensity error of cascade gamma transfer.

Gamma width and transition strength

From the experimental data of gamma intensity and electromagnetic transfer selection, the lifetime level, width level and gamma transition strength were calculated for some levels of ^{49}Ti nucleus at compound state as capturing neutron. The result showed on the table 3.

Table 3. The lifetime, width level, spin and transition strength of some level

Level (keV)	$t_{1/2}$ (s)	$\Gamma_{\gamma i}$ (eV)	E_γ (keV)	$J_i^\pi \rightarrow J_f^\pi$	$J_i^\pi \rightarrow J_f^\pi$ [3]	Transition Strength		
						$\lvert M(E(1)\rvert^2$	$\lvert M(M(1)\rvert^2$	$\lvert M(E(2)\rvert^2$
8142.50	4.89599E-16	1.34	6761.08	$1/2^+\rightarrow 3/2^-$	$1/2^+\rightarrow 3/2^-$	1.48	---	---
			6556.06	$1/2^+\rightarrow 3/2^-$	$1/2+\rightarrow 3/2^-$	11.62	---	---
			6419.04	$1/2^+\rightarrow 1/2^-$	$1/2^+\rightarrow 1/2^-$	16.39	---	---
			4966.86	$1/2^+\rightarrow 1/2^-$	$1/2^+\rightarrow 1/2^-$	24.99	---	---
			3920.73	$1/2^+\rightarrow 1/2^-$	$1/2^+\rightarrow 1/2^-$	27.02	---	---
			3475.68	$1/2^+\rightarrow 1/2^-$	$1/2^+\rightarrow 1/2^-$	1.48	---	---
			3026.62	$1/2^+\rightarrow 1/2^-$	$1/2^+\rightarrow 1/2^-$	0.06	---	---
			4713.83	$1/2^+\rightarrow 1/2^+$	$1/2^+\rightarrow 3/2^-$	---	14.92	---
			4353.78	$1/2^+\rightarrow 1/2^+$	$1/2^+\rightarrow 3/2^-$	---	20.40	---

5115.38	6.67683E-16	0.99	3733.71	$1/2^- \rightarrow 3/2^-$	$1/2^- \rightarrow 3/2^-$	---	1.40	---
			3389.66	$1/2^- \rightarrow 3//2^-$	$1/2^- \rightarrow 3/2^-$	---	3.52	---
4221.27	1.64314E-15	1.60	2839.60	$1/2^- \rightarrow 3/2^-$	$1/2^- \rightarrow 3/2^-$	---	1.64	---
			2498.55	$1/2^- \rightarrow 3/2^-$	$1/2^- \rightarrow 3/2^-$	---	2.56	---
3260.08	8.65394E-15	0.08	1674.45	$1/2^- \rightarrow 3/2^-$	$1/2^- \rightarrow 3/2^-$	---	5.51	---
			1498.43	$1/2^- \rightarrow 3/2^-$	$1/2^- \rightarrow 5/2^-$	---	1.27	---

In this result, spin and parity of some levels are different from LANL [3]. Especially, two gamma rays: 4713.83 keV and 4353.78 keV emitted from B_n to intermediate level, they are not electronic dipole, and they must is magnetic dipole. The results used to calculate the single particle model of nuclei which compares to experimental data. Thus, we conclude that ^{49}Ti nucleus can be explained by the single particle model. A comparison of ratio between theoretical result with experimental result is about 12 times (for electronic dipole), while the ratio between theoretical result with experimental result is about 1.3 times (for magnetic dipole).

V. CONCLUSIONS

By the empirical study of the cascade transfers of ^{49}Ti nucleus from ^{48}Ti(n, 2γ)^{49}Ti reaction, we measured 14 pairs of cascade transfer and arranged into nuclear scheme; in addition, the relative intensities of the transfers were presented. Using the rules of calculation of spin and parity, the possible spin and parity were calculated for experimental levels. The spins, the parities were uptodated for unsuitable levels. The results also are showed lifetime level, width level and gamma transition strength of some levels.

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